8. PERFORMANCE OF THE 707-320B AIRPLANE WITH ACOUSTICALLY TREATED NACELLES

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SUMMARY

The major performance effect of the Boeing designed acoustically treated nacelle on a Boeing 707-320B airplane powered by Pratt and Whitney JT3D-7 engines is a reduction in capacity-payload range of approximately 200 n. mi. The reduction is primarily due to the 3140-pound loss of available fuel displaced by the increased operating empty weight of the airplane. Details of airplane performance changes along with a description of the flight test program used to obtain the performance effects are included.

INTRODUCTION

The development of the Boeing treated nacelles and the acoustic results are presented by Sawhill (paper 7 herein) and Atvars, Mangiarotty, and Walker (paper 9 herein). The purpose of this paper is to present the effects of the nacelle modification on the performance of a Boeing 707-320B airplane powered by Pratt and Whitney JT3D-7 engines. The nacelle configuration changes and the relation of the changes to airplane performance are described. The flight test program used to evaluate acoustic results and airplane performance is outlined. Performance effects are evaluated by comparing measured take-off distances, cruise performance, and effect on payload range of an airplane with the modified nacelles to an airplane with the existing nacelles.

CONFIGURATIONS

Figure 1 shows the existing nacelle used on current 707 airplanes. The nacelle was developed to provide low weight and minimum cruise drag. The relatively short inlet has an 18-percent contraction from the highlight area to the throat area. The small contraction was selected for low cruise drag and requires the use of blow-in doors to provide the high-pressure recovery at the compressor face required for maximum thrust at take-off conditions. The short fan exhaust duct has small internal losses and allows the aft nacelle cowl to be very tightly fitted to the engine. Location of the nacelle forward of the wing, combined with the small cross-sectional area of the nacelle, results in minimum wing-nacelle interference drag. The forward location of the fan exhaust nozzle

results in some thrust and specific fuel-consumption penalties as a result of the scrubbing drag caused by the relatively high-velocity fan exhaust air blowing over the aft nacelle cowl.

It was necessary to alter substantially the existing nacelle design to accommodate the amount of acoustic material required to obtain the desired noise attenuation. The treated-nacelle configuration is shown in figure 2. The addition of 71 sq ft of acoustic treatment in the inlet and 267 sq ft of treatment in the fan exhaust duct requires an increase in the size and weight of the nacelle. These changes make it difficult not to incur a significant loss in airplane performance with the treated nacelles installed. The acoustic treatment in the inlet is located in the cowl wall, in two concentric rings, and in the centerbody. The inlet length was increased from 36 to 45 inches to accommodate the acoustic treatment with a minimum effect on inlet-pressure recovery. A large contraction ratio of 1.25 was used to simplify the design and provide adequate take-off performance without the use of blow-in doors. These changes contributed to some deterioration in inlet performance. A full-length fan duct with an annular nozzle was selected to provide adequate treatment surface. The relatively large flow area through the duct, designed to provide a low velocity over the acoustic lining and reduce internal losses, increased the diameter of the aft nacelle. The larger nacelle results in increased wing-interference drag. These losses are partly compensated for by the reduction in scrubbing drag with the long-duct configuration.

FLIGHT TEST PROGRAM

The performance of the treated nacelles was evaluated from measurements made during a flight test program. Tests were made to compare airplane performance with the existing nacelles to the performance of the same airplane equipped with the treated nacelles. Figure 3 shows the test airplane with the treated nacelles installed. The airplane was basically a Boeing 707-320B, a long-range, heavyweight version of the 707 series. Pratt and Whitney JT3D-7 calibrated engines were used. The airplane contained several minor modifications, including wing-tip changes and radar antennas on the upper aft portion of the fuselage that were used for other tests. These changes had a small effect on the overall airplane performance; however, since the configuration was the same for both sets of nacelles, there was no measurable effect on the incremental performance between the existing and the treated nacelles. The calibrated airplane contained instrumentation to measure both airplane performance and engine characteristics. When the treated nacelles were installed, instrumentation was included to evaluate the internal flow in one of the nacelles.

Prior to the performance flight tests of the treated nacelles, tests were conducted to insure the flight safety of the modified airplane. In-flight checks of flutter

characteristics, compressor surge, nacelle and oil cooling performance, and engine operation were made. The possibility of compressor surge was investigated during conditions of maximum sideslip, power-on and power-off stalls, engine acceleration, and during an overrotation at take-off conditions. Ground tests with simulated crosswinds up to 15 knots at 90° to the inlet were also conducted. During the safety checks and during the entire flight test program, no adverse effects were observed, and no deviations from the normal flight operating procedures were required.

The flight test program included a ground run-up and a series of flight tests at take-off, climb, approach, fly-by, and cruise conditions. Ground tests were made at power settings up to maximum take-off thrust to obtain acoustic and engine performance data. Take-offs were made at airplane gross weights of approximately 330 000 pounds and 260 000 pounds. Maximum power settings were used, and climb-out was made at velocities equivalent to $V_2 + 10$ knots where V_2 is the minimum climb speed. Runway distances and airplane altitude were measured with airplane-mounted theodolite cameras. Acoustic data, recorded by using the acoustic test range, were also obtained for tests in which the take-off power was cut back to the power required to maintain a 6-percent climb gradient when the aircraft reached an altitude of 700 feet. Approach conditions were run by using a 3° glide slope and by maintaining constant thrust settings of 4900 or 6800 pounds. Noise data for fly-by conditions were obtained for thrust settings corresponding to approach, maximum take-off, and cutback power. The airplane was flown at an altitude of 400 feet at approximately 160 knots for all fly-by conditions. Details and results of the acoustic tests are presented by Atvars, Mangiarotty, and Walker (paper 9 herein).

Airplane cruise drag tests were conducted at constant values of airplane weight divided by the ambient-pressure ratio (W/δ). Tests for values of W/δ equal to 0.8×10^6, 1.0×10^6, and 1.2×10^6 were made at Mach numbers from 0.65 to 0.88. The values of W/δ selected are representative of normal long-range cruise conditions. The largest value corresponds to the optimum high-altitude conditions. Propulsion cruise performance tests to obtain engine performance characteristics were made at an altitude of 35 000 feet at Mach numbers of 0.7 and 0.8. The engine power setting was varied on two engines while the other two engines were used to maintain test conditions.

PERFORMANCE EFFECTS

The measured ground distance required for the airplane to reach an altitude of 35 feet is shown in figure 4 as a function of airplane gross weight. The treated-nacelle configuration required about 2.6 percent more distance for 260 000 pounds gross weight and 1.6 percent for 330 000 pounds. The data were corrected to zero-wind, standard-day conditions at sea level. The measurements are consistent with test-stand data which

indicated the static take-off thrust of the treated nacelle would be about 0.25 percent less than that of the existing nacelle. During take-off, as the airplane velocity increases, the relative inlet performance of the treated nacelle decreases, and at about 100 knots forward velocity, approximately 1.5 percent less thrust is produced by the treated nacelle. The combined effects of a slightly longer take-off distance and a reduced climb gradient lead to a loss of height during climb-out. Figure 5 indicates that at a point 3.5 n. mi. from brake release, the height loss was 90 feet at 260 000 pounds gross weight and 125 feet at 330 000 pounds. The values shown were obtained from measurements made with an airplane equipped with JT3D-7 engines. If JT3D-3B engines had been used, the height loss for 330 000 pounds gross weight would have been about 90 feet.

The thrust specific fuel consumption (designated TSFC in the figure) measured during the propulsion cruise tests is plotted against net thrust $\left(F_N/\delta\right)$ in figure 6 for Mach numbers (designated M in figures) of 0.7 and 0.8. When the propulsion performance of the two nacelles is compared, the scrubbing drag associated with the existing nacelles was considered as a loss in thrust because the scrubbing drag is closely related to the fan-duct performance. Figure 6 indicates that at cruise conditions the reduction in scrubbing drag has compensated for the increased inlet and fan-duct losses and results in a 2-percent improvement in specific fuel consumption at the lower thrust settings. At the higher thrusts, the inlet losses for the treated nacelle increase and the specific fuel consumption increases to values similar to those of the existing nacelles. The airplane drag coefficients based on calculated thrust values are illustrated in figure 7 for various Mach numbers and two values of W/δ. As expected, the drag of the larger treated nacelle is greater. The increase at a Mach number of 0.8 is about 1.5 percent for a value of W/δ equal to 1.2×10^6 and 3.4 percent for a value of W/δ equal to 0.8×10^6.

The changes in specific fuel consumption and airplane drag combine to give the normalized specific range shown in figure 8. The treated-nacelle configuration shows an increase in specific range at low Mach numbers, but at normal cruise speeds a reduction is indicated. The loss is about 0.7 percent at a Mach number of 0.8 and 2.1 percent at a Mach number of 0.83 for the representative values of W/δ.

The effects of the modified nacelle on the payload-range characteristics of the airplane are defined in figure 9. A potential retrofit version of the treated nacelles, including thrust reversers, is estimated to increase the operating empty weight of the airplane by 3140 pounds. The resulting displacement of available fuel contributes the major part of the loss of 200 n. mi. in capacity-payload range. About 25 percent of the range loss is caused by the change in specific range. The curve shown is for international fuel reserves and long-range cruise techniques. The increased operating empty weight has not affected the maximum permissible payload because the distribution of the extra weight of the treated nacelles across the wing span allows a corresponding increase in

maximum zero-fuel weight. The long-range cruise technique is associated with cruise at a Mach number of 0.8. If a minimum-cost cruise technique is used, where the cruise Mach number is about 0.83, the reduced specific range at this Mach number increases the loss of capacity-payload range to 225 n. mi. If domestic fuel reserves are considered, the range loss is increased an additional 25 n. mi.

CONCLUSIONS

The changes in measured performance obtained with the Boeing designed, acoustically treated nacelles installed on a Boeing 707-320B airplane are summarized as follows:

1. The major performance effect of the treated nacelle is that the capacity-payload range is reduced approximately 200 n. mi. The reduction is primarily due to the 3140-pound loss of available fuel displaced by the increased operating empty weight of the airplane.

2. During take-off the height at a distance of 3.5 n. mi. from brake release is reduced 125 feet for an airplane of 330 000 pounds gross weight.

3. At cruise conditions, the specific range is reduced by 0.7 to 2.1 percent.

4. No change is required in flight operating procedures with the modified airplane.

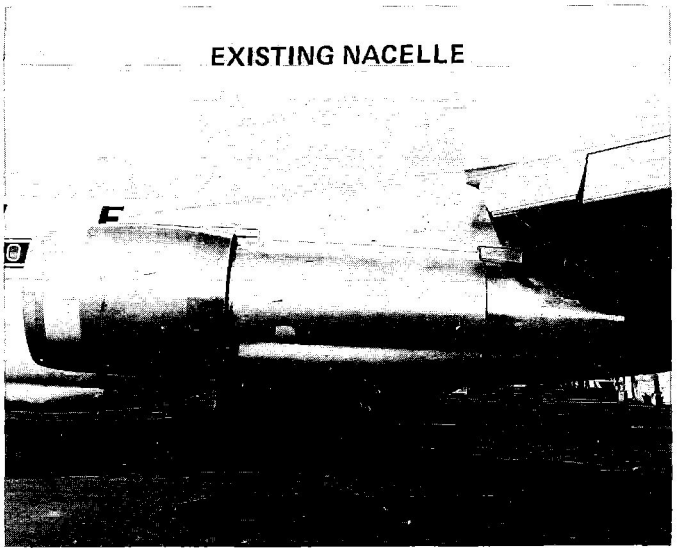

Figure 1

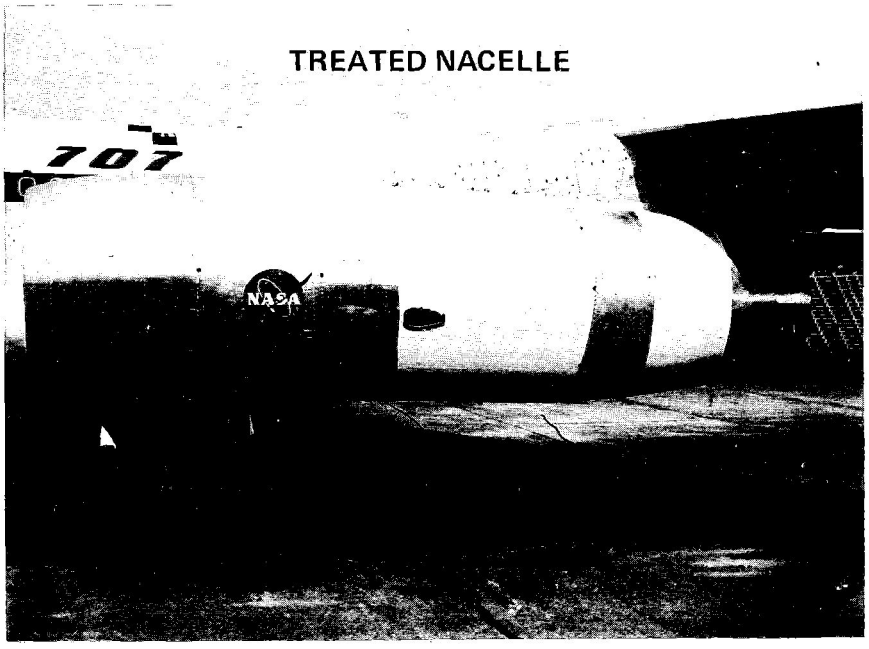

Figure 2

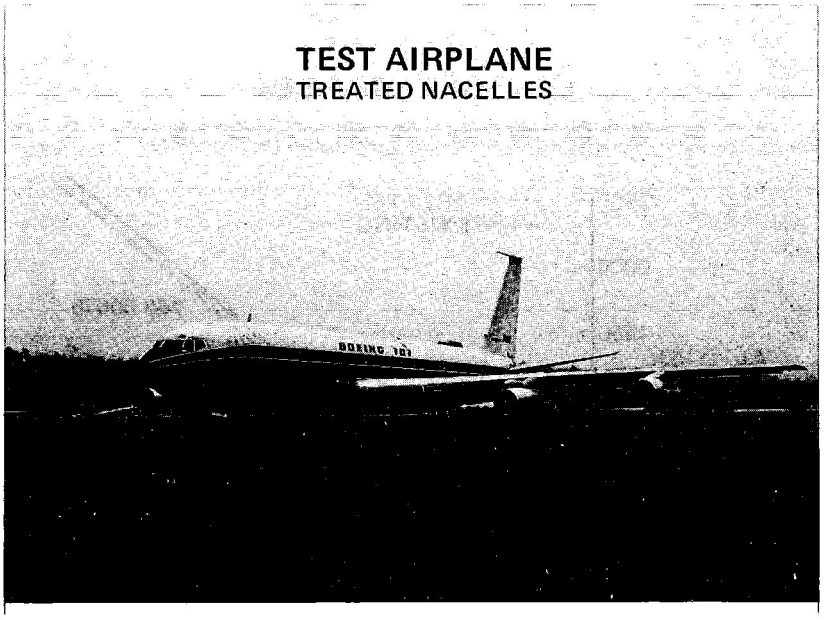

Figure 3

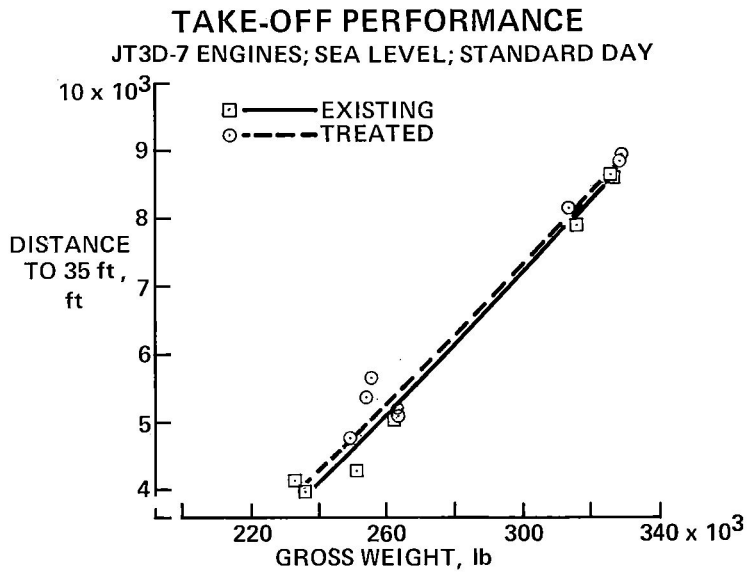

Figure 4

TAKE-OFF PROFILES

JT3D-7 ENGINES; SEA LEVEL; STANDARD DAY

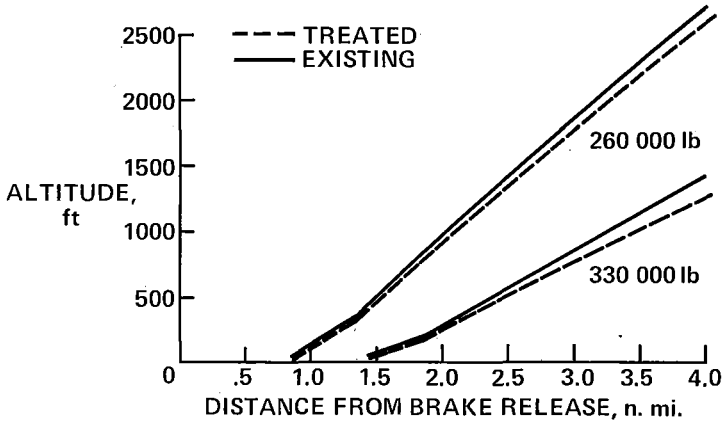

Figure 5

FUEL CONSUMPTION

35 000 ft

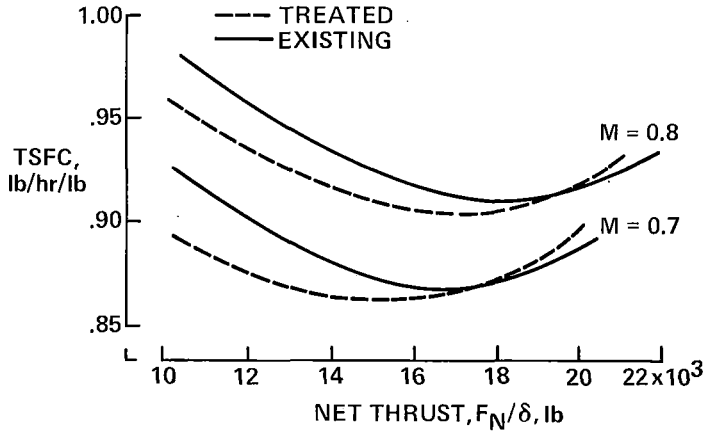

Figure 6

CRUISE DRAG

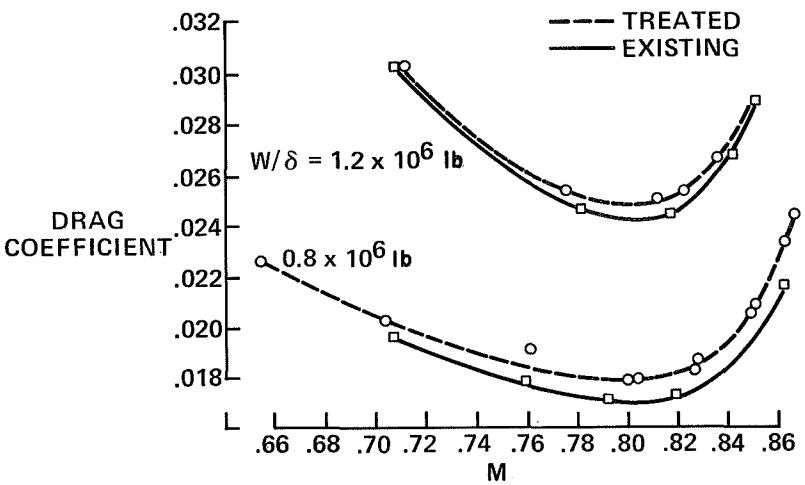

Figure 7

SPECIFIC RANGE

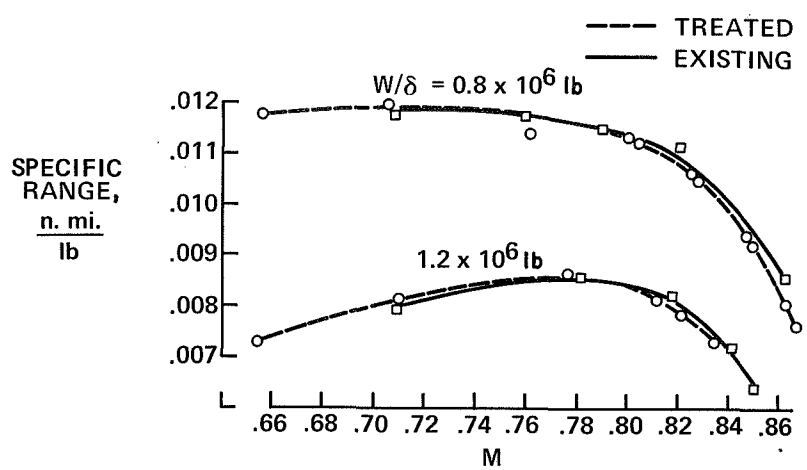

Figure 8

PAYLOAD RANGE

LONG-RANGE CRUISE ; ATA INTERNATIONAL RESERVES

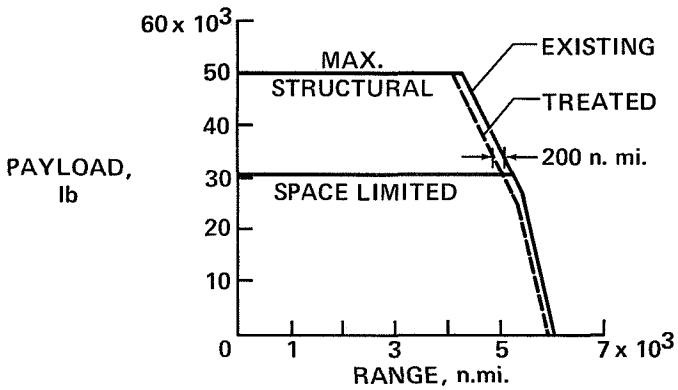

Figure 9